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# Identification of Potential Sites for Housing Development Using GIS Based Multi-Criteria Evaluation in Dire Dawa City, Ethiopia

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**Abstract**

Site suitability analysis for specific project is the preliminary tasks in context of modern urban land use planning and development. However, site analysis by its nature is the complex process and involves consideration of multi-criteria decision making limited not only to physical condition of urban land-uses, but more attention should be given to integrate socio-economic and environmental factors. GIS based Multi-Criteria Evaluation (MCE) and Analytical Hierarchy Process (AHP) provides a wide range of powerful tools capable to transforms, combines sophisticated geographical data with value judgments among conflicting criteria along with sets of alternatives. The present study modeled suitable building sites for housing development in Dire Dawa City. Eleven factors such as land-use/land-covers, built-up, slope, flood sheets, road, aspect, airport, railway, soil, population density and proximity to urban center were evaluated and prioritized as per judgment of urban planning experts. The influencing weights among factors has been computed using Analytic Hierarchy Process (AHP) in IDRISI 32 software.

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The overall Consistency Ratio (CR) of the module was 0.08 % and fulfilled the tolerable threshold (CR ≤ 0.10). Finally, the Weighted Linear Combination (WLC) function of ArcGIS model builder has been applied to generate suitability map. The finding of the study revealed that, about 5.42 Sq.km (8.04%), 25.58 Sq.km (37.90%), 10.68 Sq.km (15.83%) of total urban landscape is very highly suitable, highly suitable, and moderately suitable respectively. Thus, the study implies the effectiveness of integrated GIS and MCE tools to handle site suitability analysis aimed at to identify environmentally safe and economically feasible sites to fulfill housing demand. It also provides invaluable input for geo-spatial decision support system by addressing uncertainty to prioritize where additional house should be developed.

***Keywords:*** Site suitability analysis; Multi-criteria evaluation; Analytical hierarchy process; Consistency ratio Weighted linear combination.

## 1. Introduction

Urbanization is one of the most dynamic geographical phenomena in history of mankind and represented by sets of two contradictory perspectives. On the one hand, urbanization act as an engine and indicator of transformation from traditional rural economy, both physically and functionally, is widely recognized for enormous socio-economic improvements of the residents. According to [36], urban dwellers have the opportunity to access better dwelling infrastructure and facilities, social-wellbeing, and improved living standards as compared to their rural counter parts. However, the positive aspect of urbanization in case of developing countries were overshadowed due to lack of proper planning domains accompanied by acute socio-economic and ecological impacts [35, 37, 4, 16, 1, 12].

The intensified demand for additional land for the establishment new projects; development and redevelopment of previous urban infrastructures and industrial development were among the major triggering agents for subsequent urbanization process. However, the push factors like urban population growth with pull factors particularly of economic progress are the two most underlying causes for considerable urbanization [29, 27]. Since spatial patter and changes over time of urban patch is indispensable, understanding factors elicited the process and proper physical planning is compulsory to meet the present and future needs of the cities. However, in perspectives of spatial planning and decision making process, reliable and accurate urban land information has attracted a great deal of attention and undoubtedly plays the pivotal role to narrow the gaps between the provision and demand for basic urban infrastructures [17].

Similarly in Dire Dawa City, spurred by rapid population growth and industrialization has brought unprecedented urbanization process over the past few decades. As per the national population and housing census of 1994, the city was the home of about 173,188 and about 233,224 during the census period of 2007respectively[8]. As a result, in much recent years, the city has experienced the intense demand for residential area following footstep of population growth. Moreover, the rising demand for residential housing land [36], even tends to push urban dwellers to expand into different corridors of the city, even ignoring topographic factors such steeper slopes and flood prone areas. According to [31,7], since urbanization process and population growth is inevitable, identifying suitable building site for housing development [3], could play an important role to effectively satisfy the demand of urban dwellers.

Hence, there exists a definite spatial planning intervention for comprehensive residential housing development site identification in the city. However, there was still the debate exists on how to uphold effective urban land use planning  in one hand, and maintaining proper natural resource conservation measures[15]. The rapid progress made in modern geospatial science like GIS augmented with Multi-Criteria Evaluation (MCE) techniques nowadays have been put forward with series of applications and capability to solve the complexity in any spatial decision making process. This study focused on identifying potential sites for new residential housing development in Dire Dawa City. The result drawn from study may serve as spatial decision support system with ample potentials to satisfy the housing demand for drastically increased population of the city.

## 2. Description of the study Area

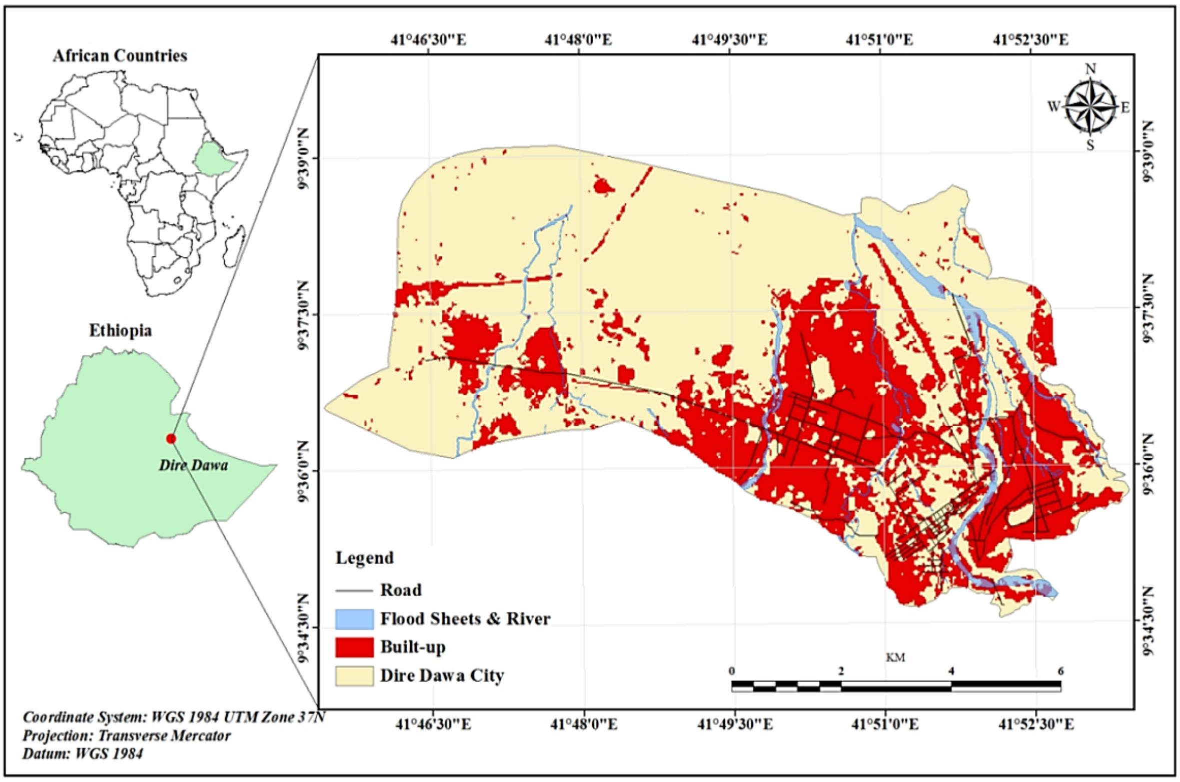


**Figure1:** Location map of study area

The study area (Fig.1) viz. Dire Dawa City is extends between geographic coordinates of  at 9° 33′ 20″N to 9° 40′ 00″N latitude and 41° 45′ 00″ E to 41° 53′ 00″ E longitude at some 515 Kilometers away from Addis Ababa City, the capital City (Figure1). The maximum elevation of the city is 1321 meters above mean sea level. Owing to its geographical proximity to international port of Djibouti within the distance of about 333 Kilometers, the city is one of the preferred destinations for trade and industry. The city had been restructured to nine urban *Kebele* (administration units) having the total area coverage of about 69 $km^2$.  As per the national population and housing census of Ethiopia, in 1984 the total population of the city was estimated to 99,980. In the second and third national census periods of 1994 and 2007 the total population of the city is about 173,188 and 233,224 respectively [8].

## 3. Data and Methods

### *3.1. Geospatial data*

The study was mainly supported by geospatial datasets gathered from different sources. In addition primary data were gathered from field survey, geospatial datasets such as ASTERT Global elevation Model (DEM) with 30m x 30m spatial resolution, Structural plan of the city, Landsat image and Soil map were incorporated. Moreover, demographic data was collected from central Statistics Agency (CSA) to analyze population density per *Kebeles* using GIS shape files.  All data were projected to WGS1984 spheroid, Universal Transverse Mercator (UTM) Zone 37 North.

**Table1:** Geo-spatial data source

| Data | Sources |
|---|---|
| Soil Class Map | FAO(1997) |
| Structural Plan | Dire Dawa City urban Land Management office |
| Landsat8 (OLI-TIRS) | USGS website: http://www.usgs.gov/. |
| DEM | ASTER Global DEM website:<br><br>http://www.gdem.aster.ersdac.or/jp /search.jsp. |
| Demographic Data | Central Statistics Agency (CSA) |

### *3.2. GIS-based multi-criteria evaluation*

The study used the methodological framework of integrated GIS and Multi-criteria evaluation (MCE) techniques to evaluate site suitability for housing development in Dire Dawa City. GIS and Multi-criteria evaluation (MCE) has been globally recognized for their outstanding capacities in spatial decision support system in site suitability analysis [38, 20] frequently applied to solve complex decisions to boost proper land-use planning [20]. According to [20], “MCE is a procedure that typically multiplies conflicting and corresponding criteria that are essential to be evaluated in decision-making”. In general the basic advantages of using MCE method is the possibility to evaluate complex and multiple factors at different scales and aggregated to produce a composite map portray suitable land for a particular project.

### *3.3. Determining suitability criteria and Factors*

According to [31], “site selection requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use”. According to [30], “MCE is a procedure that typically multiplies conflicting and corresponding criteria that are essential to be evaluated in decision-making". In general the basic advantages of using MCE method is the possibility to evaluate complex and multiple factors at different scales and aggregated to produce a composite map portray suitable land for a particular project. Hence, multi-criteria evaluation of demands identification of local factors that best fits to select candidate areas to meet a defined use [28]. Therefore, "site suitability is the process of understanding existing site qualities and factors which will determine the location of particular activity" [33].This requires analysis of wide-ranging and consistent datasets to achieve the objective. Hence, for the purpose of ensuring the maximum society's benefits the present study considered the real urban situations of the study area with eleven economic and environmental factors supports identification of potential sites for housing development.

### *3.3.1. Environmental Factors*

**Aspect (Topography):** Aspect generally refers to the horizontal direction to which a mountain slope faces. Aspect identifies the steepest down slope direction from each cell to its neighbors, where, the value of the output raster data set represents the compass direction. Hence, the eastern and western direction was considered to be more suitable

**Soil**: According to [14], the soil class of the city were categorized into three i.e. Calcaric Fluvisols (FLc) rich with alluvial deposit (Calcareous material), Eutric Regosols (RGe) mantle of loose material overlying the hard core of the earth and Leptosols (LP) weakly developed shallow soils and lacks hard rock. Thus, the soil class was reclassified based on their properties and suitability for housing development.

**Flood area**: From the goal of safety the candidate suitable site for residential housing area should be free from risk aroused by river flooding during rainy seasons. Hence, river and river layers were clipped from structural plan of the city. According to the structural plan of the city, no any development is permitted within 30 meter limit in both sides of river and flood sheet areas. Thus, the distance far away from river channels were more suitable for housing.

**Distance from airport**: In order to minimize noise disturbance of aircraft during landing and takeoff operation the candidate suitable site for housing development should be far away from airport sites. Hence, residential site must be situated at the minimum buffer distance of 3 km away from the airport [31].

**Land-uses/land-cover:** The next important parameters considered was land-uses/land-cover map analyzed from Landsat 8 (OLI-TIRS) satellite image of 2015. The land use of the city has been classified as follows: Plantation, Built-up, Bare land, Shrub and Agriculture. In this study, built-up area is restricted (unsuitable) since it is already developed area, whereas, bare land is given high preference followed by shrub land for new housing development.

### *3.3.2. Economic criteria*

**Slope:** As far as the topography of the study area is concerned, since the steeper slope demands relatively gentle slopes with flat terrain were much preferable. Contrary, steep slope area eventually increased cost of construction. Thus, an area with slope between 2% -15 % is suitable for housing.

**Accessibility to road and railway:** Accessibility to road is one of important criterion in site suitability to facilitate the mobility and linkage between the settlement sites [3]. Hence, Evaluation of accessibility to public infrastructure in terms of distance from a particular location using particular transportation must be taken into consideration while selecting suitable site for housing [46]**.** At any rate, the road accessibility is the most important factor and any housing development project must be confined within 1-5 km radius [31, 47]. However, [5], revealed that road distance may not strongly affect suitable site i.e., the more the site is closer to the street the more likely suitable for residential house because of transportation access with short distances. For this particular study, the Euclidian distance from both sides of the main road is generated and reclassified. Moreover, [47], stated that housing should 200 meter far away from the railway line to minimize noise disturbance and safety of the residents. Hence, buffer distance of 200 meter on both side of the rail line was analyzed and reclassified.

**Distance from built-up (developed) Area**: The built-up area was extracted from land-uses to incorporate in the analysis. Hence, Urban built-up areas were considered since the new urban development for housing should be located closer to the existing built-up to minimize the occurrence of urban sprawl and create coherence with pre-developed area. Thus, an area adjacent to existing built up area is much preferable for residential housing.

**Proximity to urban center:** The central part of the city was considered suitable for urban development. In general, eight kilometer buffer distance from mean urban center is needed to cover the city and those areas closer to currently developed land are more suitable than areas farther from developed. Thus suitability index for housing development will decreases as the distance from urban center is gradually increasing.

**Population Density:** The census data of the city in 2007 was used to compute population density (people per square kilometer) for each *Kebele* in ArcGIS 10 software. Hence, the areas with low population density were much preferable for new housing development sites.

### *3.4. Analytical Hierarchy Process (AHP)*

GIS based multi-criteria site suitability analysis involves geographical representation and classification of appropriate parameters based on their relative importance and suitability score. According to [45], it is extremely difficult to assign relative weights of multi-factors incorporated in site analysis to identify favorable sites for particular land uses. But, AHP is the rational decision support system developed to allow both qualitative and quantitative information to treat complex and multi-index systems [42, 48]. Moreover, AHP is multi-indices comparison method in which each criterion is compared with all others to reflect their relative importance. The weight of each factor is computed using Principal Eigen Value of squire reciprocal matrix using Analytical AHP in IDRISI software [24, 41]. The Eigen value in AHP lies between 1 and 9; Where, class 1 = represents equal preference between two factors and class 9 stands for a factor extremely preferred over the other [25]. This can be done based the relative importance of each layers stated in literatures related to the study and judgment of planning experts familiar with urban environment of the study area [25, 11,40]. Moreover, the

Consistency Ratio (CR) has been estimated to check the degree of consistency in the aggregate group judgments made by expert's [13, 41]. According [44, 39, 6], the CR can be as follows.

$$CR=\frac{CI}{RI} \quad (1)$$

Where CI is consistency index; RI is the random index - the average result of consistency index depending on the order of the matrix.

$$CI= \frac{\lambda_{max-n}}{n-1} \quad (2)$$

Moreover, the Consistency Index (CI) is simplified as:

Where, $\lambda_{max,}$ is the largest or Principal Eigen value of the matrix; and n stands for the order of the matrix.

Accordingly, the CR does not exceed 1 i.e. CR of ≤ 1 is considered as reasonable to accept [44, 19, 39]. However, [34] stated that, the CR > 0.10 is an indicator of inconsistent judgments and needs to revise the matrix. Furthermore, Fuzzy Membership Functions such as Sigmoidal, Linear and J-Shape were used to standardize the criterion scores [23, 7]. The Fuzzy Membership Function is commonly measured on a byte scale and quantified into continuously measurable unit's ranging between 0 – 255, where, 0 is representing land unit not suitable and 251 is perfectly suitable is most suitable.

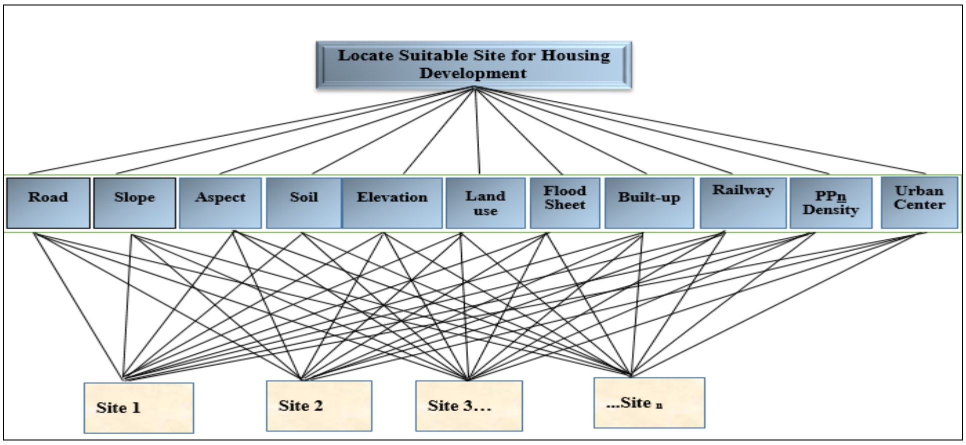


**Figure2:** methodological frame work of pairwise comparison of suitability factors in analytical hierarchy process. Source: [43].

### *3.5. Weighted linear combination*

According to [9], "GIS-based MCA includes two major methods: weighted summations procedures and Boolean overlay operations". To date, the Weighted Linear Combination (WLC) could permit evaluation and combination of criterion standardized to a common numeric range to determine the composite output map layer

[32]. In this particular study, the final suitability map was the result of weights and rated suitability scores of each parameter analyzed in ArcGIS spatial analysis model builder tool. The Weighted (WLC) was computed using the formula adopted by [45, 5, 26] as:

$$S = \left(\sum_{i=1}^{n} W_i \times X_i\right) \times \prod c_j \qquad (3)$$

Where:

S -Suitability Index for housing development

Σ - Sum of weighted factors

n- Number of Criteria

$W_i$-Weights of each criteria i

$X_i$ -Score of the criteria

Cj - constraints (Boolean map represented with values of 0 or 1)

Π - Product of constraints (1-suitable, 0-unsuitable)

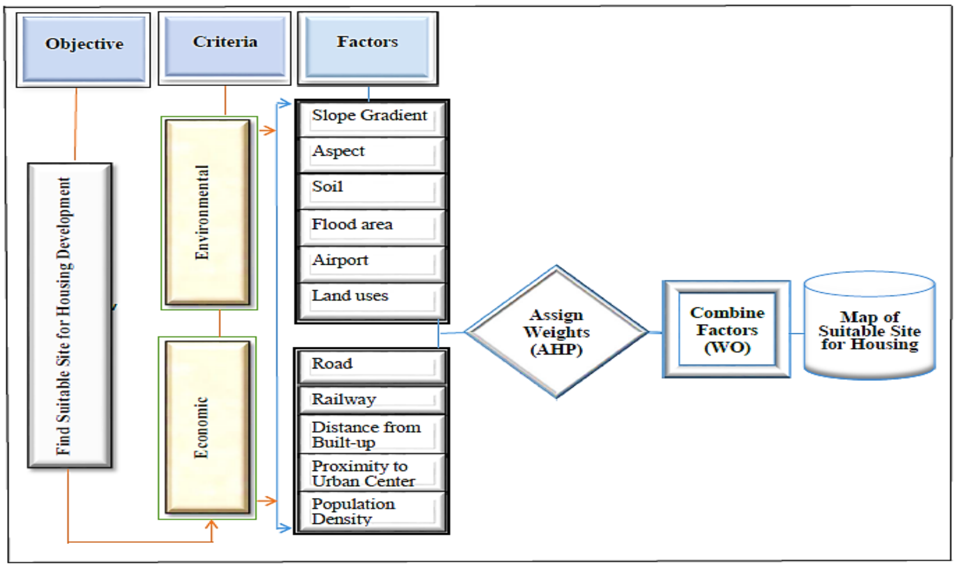


**Figure3:** weighted linear combination procedure of housing development site identification

To end a summary of all grid cells includes five suitability classifications, where “0” represents “restriction”, 1 represent “low”, 2 represents “moderate” class , 3 represents “High” class and 4 represents “Very high” suitability index for housing development.

## 4. Result and Discussion

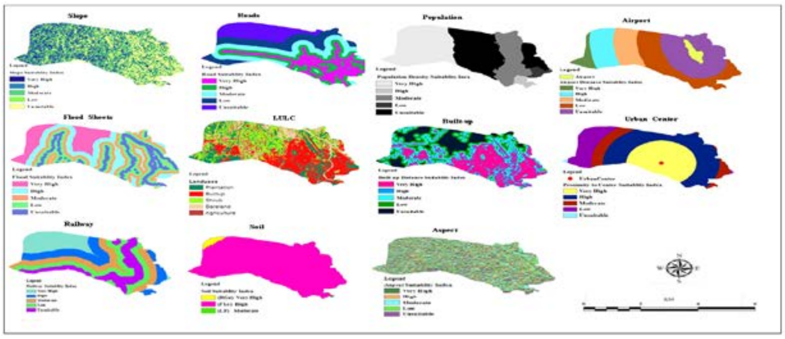

**Figure4:** reclassed suitably factors for housing development

### *4.1. Standardized suitability factors*

### *4.2. Weights and consistency ratio*

The prioritization of the suitability criteria and the influencing weights computation was the most important step in site suitability analysis. Hence, the influencing weight of each criterion was generated using 9 class values applied in each factors based on their relative importance [42]. The eigenvector weights of eleven parameters are computed using decision support wizard IDRISI 32 software [23] with the supports of expert's judgments [18]. This technique is very important in case of problems incorporate and deals with number of alternatives appeared in raster data model format [22].

**Table2:** Pairwise comparison of eleven factors in nine point continuous scales

| Scale | Slope | LULC | Road | RW | APD | BU | Soil | River | PPD | PUC | Aspect | Weights | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slope | 1 | | | | | | | | | | | 0.2598 | 25.98 |
| LULC | 1/3 | 1 | | | | | | | | | | 0.1639 | 16.39 |
| Road | 1/5 | 1/3 | 1 | | | | | | | | | 0.1601 | 16.01 |
| RW | 1/7 | 1/5 | 1/3 | 1 | | | | | | | | 0.1039 | 10.39 |
| APD | 1/4 | 1/3 | 1/2 | 1/1 | 1 | | | | | | | 0.1315 | 13.15 |
| BU | 1/5 | 1/4 | 1/3 | 1/2 | 1/1 | 1 | | | | | | 0.0573 | 5.73 |
| Soil | 1/9 | 1/7 | 1/5 | 1/3 | 1/2 | 1/1 | 1 | | | | | 0.0387 | 3.87 |
| River | 1/9 | 1/7 | 1/5 | 1/4 | 1/3 | 1/2 | 1/1 | 1 | | | | 0.0300 | 3.00 |
| PPD | 1/9 | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1 | | | 0.0225 | 2.25 |
| PUC | 1/9 | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1/1 | 1 | | 0.0175 | 1.75 |
| Aspect | 1/9 | 1 | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1/1 | 1 | 0.0147 | 1.47 |
| CR: 0. 08 (Consistency is Acceptable) | | | | | | | | | | | | ∑= 1.0 | 100 |

LULC= Land-use/Land-cover; RW=Railway; APD=Airport Distance; BU=Built-up,; PPD=Population Density; PUC= Proximity to urban center

The consistency ration computed using pair-wise comparison matrixes for all considered factors resulted 0.08, which is fall with acceptable threshold (CR ≤ 0.10) [44, 20, 39].

**Table3:** The Standardized Suitability Factors and Influencing Weights

| Factors | Ranges | Area($Km^2$) | Coverage (%) | Weight % | Index |
|---|---|---|---|---|---|
| Slope (%) | 0 - 2 | 13.8069 | 20.12 | | Very High |
| | 2 - 8 | 14.5683 | 21.23 | | High |
| Road | 0-1000 | 13.68 | 20.04 | | Very High |
| | 1000-2000 | 14.10 | 20.58 | | High |
| River & | 0- 500 | 12.62 | 18.41 | | Very High |
| Flood areas | 500 - 1000 | 14.85 | 21.65 | | High |
| Land uses | Plantation | 15.68 | 22.67 | | Very High |
| | Built-up | 23.28 | 33.67 | | High |
| Rail way | 0- 500 | 12.62 | 18.41 | | Very High |
| | 500 - 1000 | 14.85 | 21.65 | | High |
| Population | 0- 13715 | 25.11 | 37.89 | | Very High |
| Density | 13715 - 20693 | 1.80 | 2.41 | 5.73 | High |

**Table3:** Continued

| Factors | Ranges | Scores | Area(Km$^2$ | Coverage (%) | Weight | Index |
|---|---|---|---|---|---|---|
| Airport | 0-1000 | 1 | 25.43 | 37.11 | | Very High |
| | 1000-2000 | 2 | 19.31 | 28.13 | | High |
| Built-up | 0 - 500 | 5 | 22.34 | 32.57 | | Very High |
| (Developed area) | 500 -1500 | 4 | 9.18 | 13.39 | | High |
| Soil Class | Calcaric Fluvisols (FLc) | 2 | 67.10 | 97.81 | | High |
| | Eutric Regosols (RGe) | 3 | 1.49 | 2.17 | 16.01 | Moderate |
| Urban Center | 1000 - 3000 | 5 | 22.10 | 23.18 | | Very High |
| | 3000 - 5000 | 4 | 27.65 | 40.31 | | High |
| Aspect | 1 - 45 | 1 | 13.69 | 19.96 | | Very High |
| | 45 - 131 | 5 | 13.72 | 19.97 | | High |

### *4.3. Weighted linear combination*

The weight overlay function with 1 to 5 scales has been executed in model builder tool of spatial analysis tool docked in arc tool box of Arc GIS to identify potential sites for new housing development sites.

Suitability map= Σ [Criteria Map * Weight]

Suitability map = ([reclassed slope] * 0.2598) + ([reclassed land-use] * 0.1639) + ([re-classed road] * 0.1601) + ([re-classed railway] * 0.1039) + ([re-classed distance from airport] * 0.1315) + ([re-classed built-up distance]* 0.0573) + ([reclassed soil] * 0.0387) + ([reclassed river & flood sheet] * 0.0300) + ([re-classed population density] * 0.0225) + ([re-classed proximity to urban center] * 0.0175) + ([re-classed aspect orientation]* 0.0147))

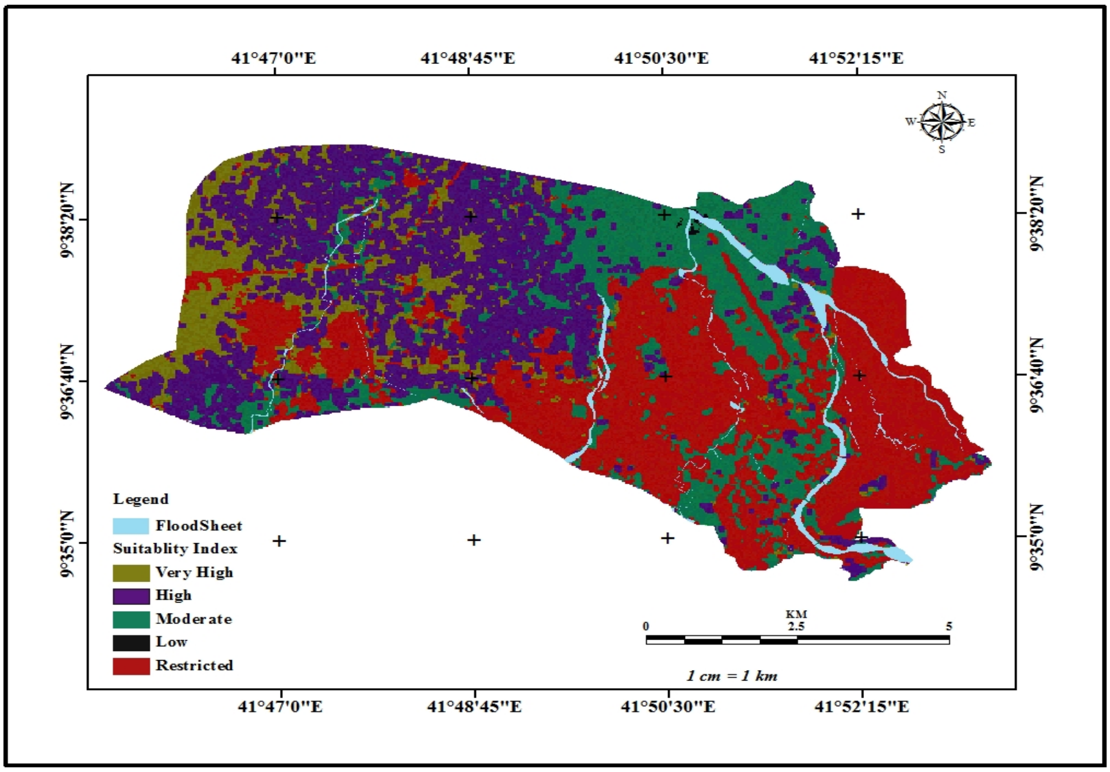


**Figure5:** Site Suitability Map for Housing Development in Dire Dawa City

**Table4:** Housing suitability index and area coverage

| Class | Suitability Index | Area(Sq.km) | Coverage (%) |
|---|---|---|---|
| 4 | Very high | 5.42 | 8.04 |
| 3 | High | 25.58 | 37.90 |
| 2 | Moderate | 10.68 | 15.83 |
| 1 | Low | 0.05 | 7.34 |
| 0 | Restricted | 25.75 | 38.16 |

The results have indicated candidate areas potentially suitable for housing development within the city (Figure 5 and Tables 5. Accordingly, ‘Very high’ class contributes about 5.42 $km^2$ (8.04 %), whereas, ‘highly’ class accounts for about 25.58 $km^2$ (37.9). Meanwhile, under the class of ‘Moderate’ there is potential for about 10.68 $km^2$ (15.83 %) additional land to be used into housing development. However, about 0.05 $km^2$ (7.34%) land have been classified as ‘low’ and 25.75 $km^2$ (38.16%), are currently ‘unsuitable’ for housing development purpose.

## 5. Conclusion

The main objective of the study was to identify suitable housing development sites in Dire Dawa City, Ethiopia, using GIS-MCE and AHP. Hence, eleven environmental and economic factors which have principal effect on site selection for housing development were identified. These includes, slope, land-uses, road, railway, airport, built-up, soil, river and flood sheet prone areas, population density, proximity to urban center and aspect. Accordingly, about 5.42 Sq.km (8.04%), 25.58 Sq.km (37.90%), 10.68 Sq.km (15.83%) of total urban landscape is very highly suitable, highly suitable, and moderately suitable respectively. The finding of the study, apart from demonstrating the effectiveness of GIS based multi-criteria evaluation techniques, it may serve as spatial decision supporting system with enormous potentials to address the uncertainty about where additional house should be developed in the city. Moreover, it may significantly serve as decision support tool serving as guideline to mitigate further environmental hazards besides encouraging authorities to apply GIS platform to support to safeguard sustainable urban land-use management.

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